ISSUE # 10 SEPTEMBER 1999

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Main features

Big Picture Science

The Science Newsletter for Montessori Teachers of 6-15 yr-olds #10 Sept. 1999

The Geologic Cycle

The Earth's surface is simultaneously being built up and broken down

Although the Earth under our feet seems fairly constant, it is always being reshaped. When students understand that the Earth's surface is dynamic, and shaped by internal and external forces, they have a better picture of Earth's crust and its history.

Helping your students see the **dynamic nature of the Earth's surface** is a challenge. The process is generally happening so slowly that we cannot see it. It is only in natural disasters that the Earth's surface changes quickly. The immense time needed to build and tear down mountains is hard to grasp.

Even harder is the idea that **all the material on the Earth's surface has undergone changes**, sometimes many of them, in the distant past. This includes the rocks around your school and homes. Two books I've listed in the references can help you introduce this idea. They are *The Big Rock* by Bruce Hiscock and *The Pebble in My Pocket* by Meredith Hooper.

For older students there is the *Roadside Geology* series. These books have an overview of the geological events as well as descriptions of structures you can see from major highways. They are available for these states: AK, AZ, CO, ID, MT, NM, NY, CA, OR, PA, TX, VT, NH, VA, and WA.

Change always involves energy. There are two sources of energy behind the changes at the Earth-atmosphere interface. The **sun's energy** drives the hydrologic cycle. It also causes the differential heating that results in winds. The heating and cooling of rocks contributes to their cracking and breakage. Water freezing and thawing in those cracks accelerates the process.

The **second source of energy is the Earth itself**. **Heat from the interior of the Earth** drives the movement of tectonic plates. This heat has three sources, 1) the collision of planetesimals when the planet formed, 2) the sinking of the heavier elements to the center of the Earth and their solidification, and 3) the ongoing decay of radioactive isotopes within the Earth. Convection moves the heat from the Earth's core to the base of the lithosphere. The plates of the lithosphere ride on hot, semi-molten rock of the asthenosphere.

Earth's gravity pulls down whatever is built up on the surface. It also provides the force to make continents rise and tectonic plates dive.

Together these forces produce the rock cycle. In my research, I found a linear version of the rock cycle that I think students will understand more easily than the traditional circular diagram. It appears on page 4. The source is a textbook, *Earth: An Introduction to Geologic Change* by Judson and Richardson.❖

Happy new school year!

Thank you for subscribing this year. Many of you sent topics you would like to see me address in newsletters. This was very helpful.

The requests included physics, astronomy, electricity, ecosystems, protist kingdom, and prokaryotes. Several of you had questions, which I will attempt to answer in issues this year.

This issue continues the Earth science that I began in issue #9. As I finished #10, I realized that I left out one big factor in changing Earth's surface – activities of humans. We actually move more of the planet's surface than rivers, glaciers, and wind put together. I hope we know where we are going with all that earth!

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Building up structures – the tectonic cycle

Plate tectonics. The major process for building new structures is plate tectonics. The lithosphere of the Earth is broken into about 14 plates that slowly move across the asthenosphere. "Tectonic" comes from a Greek word meaning "building" or "construction". Several tectonic processes occur as the plates move. These include upwelling of magma, earthquakes, volcanoes, subduction (sliding of one plate underneath another), and warping, folding, and faulting of the crust. While most changes occur at plate margins, there are also uplifts in the center of continents.

The **life cycle of a plate** starts at a spreading center, where two plates are moving apart. Here new material moves up from the asthenosphere and builds onto the edges of the plate. The new section of the plate will slowly move away from the spreading center, followed by more magma welling up and adding to the plate margin. There are spreading centers in each of the oceans. A map of the ocean floor shows these as ridges of undersea mountains. The spreading centers also show up on maps of earthquakes, since many earthquakes occur as the plates spread apart.

If material is added to a plate in one location, it has to be subtracted somewhere else or the plate must grow. In the Pacific Ocean, new plate material is added at the East Pacific Rise. The oldest material is subducted at the continental margins or under other ocean plates in the west Pacific. The plates in the Pacific Ocean carry only oceanic crust, but the Atlantic plates (and most others) have both continental and oceanic crust. The new material added at the Mid-Atlantic ridge widens the Atlantic Ocean, and pushes North America and South America farther from Europe and Africa.

Note that the **oldest ocean plate material is much younger than the oldest continental** material. The formation of the continents is not well understood, but each landmass has a core area of ancient crystalline rocks. This core is called the craton. The continent grew as plate movements added volcanic islands and other fragments to the margins of the craton. Plate tectonics as we know them began about 2.5 billion years ago at the transition between the Archean and Proterozoic Eras. It is hard to tell how things happened before that time, since the rock and tectonic cycles have changed the original materials so much.

There are other **differences between the crust under the oceans and** that under **landmasses**. The oceanic crust is thinner, averaging about 5 km as compared to 30-60 km for continental crust. Basalt, which is high in magnesium and iron and low in silica, makes up much of the oceanic crust. This mafic rock is denser than the granite that makes up much of the continental crust. When plates of the two materials come together, the heavier oceanic crust dives (subducts) beneath the thicker, less dense, continental crust. When two oceanic plates meet, one subducts beneath the other. See the section below on mountains for further description of the events at converging plate boundaries.

The story changes **when two continental landmasses converge**. Then there is a great deal of folding of the crust and only the lower layers of the plates move deeper. Between the two plates the land is pushed upward. This is the process that has formed the highest mountains in the world, the Himalayas. The plate carrying the Indian subcontinent crunched into Asia, another continental plate. The land was folded, faulted, thrust over other land, and lifted up. When continental plates collided as Pangaea formed, the Appalachian Mountains formed. They were originally connected to the Altas Mountains of northwest Africa, but the two parted when the Atlantic Ocean opened up in the Jurassic period.

As oceanic plates collide with continental plates, **fragments of land** may be **pressed onto the continent**. These pieces, called **terranes**, are much smaller than a continental plate. They may be fragments of the ocean floor, volcanic islands, or leftover pieces of continental crust. The process of shoving them onto the margin of a continental plate is called accretion and they are called accreted terranes. The west coasts of Canada and the south coast of Alaska have several of these accreted terranes. North of San Francisco, in the Franciscan terrane, you can find hills made of chert with occasional pillow basalt, both of which were formed on the sea floor.

When a plate descends back into the mantle, it melts. The magma that results from melting an oceanic plate has water and sediments added, and is less dense than the magma at spreading centers. Masses of it rise up underneath the other plate. If the second plate is also oceanic, an arc of volcanic islands form. This is the process that produced the Aleutian Islands, Java and adjacent islands in Indonesia, the Philippine Islands, and Japan.

Most of the building action on the Earth's surface happens at plate margins, but other conditions also build new structures. **Hot spots** are places where heat flows up from deep in the mantle near its boundary with the core. As a plate moves over the hot spot, magma may be extruded. If the plate is oceanic, this forms volcanic islands, such as the Hawaiian chain. The row of islands formed because the hot spot is stationary and the overlying plate moved. Hot spots lie under landmasses as well as ocean. A hot spot under Yellowstone National Park drives the geysers and other geothermal activity there. Iceland has both a plate spreading center and a hot spot under it. Hot spots do not always extrude magma. When they do, it can be enormous in quantities, producing flood basalts. The magma of hot spots has low viscosity. It sometimes flows from long cracks (fissures) and covers large areas with repeated layers, building up

Building up structures – the tectonic cycle (continued)

very large plateaus of basalt. The Deccan Traps of India, the Siberian Traps, and the underwater Ontong Java Plateau are major flood basalt deposits. The Columbia Plateau of the northwestern US was formed by the same hot spot that now lies under Yellowstone.

When you present plate tectonics in the classroom, good illustrations are a must. This is one of those "a picture is worth a thousand words" situations. Many books have diagrams of the events in the tectonic cycle. See the references for examples.

Project Earth Science: Geology (see references) has activities for modeling the processes of plate tectonics. You can use a substance such as silly putty to demonstrate the not-quite-liquid nature of the asthenosphere. A mixture of cornstarch and water with wooden blocks on top provides a model of plate movement over the asthenosphere. There is an activity to demonstrate convection, the process that carries heat from the interior of the Earth to the asthenosphere.

Mountains. When we think about building structures on the Earth's surface, we often think about mountains. Geologists call the process of mountain building orogenesis. An episode of mountain building in the Earth's past is called an orogeny. "Oro" is a Greek word for mountain; "genesis" means "origin" or "birth". There are several types of orogenies. They happen over several million years of time. Mountains can be roughly classified into three main types.

Fold mountains– As the name implies, these mountains form when the crust is folded. They form when plates converge. Crust caught between two continental plates gets crushed and folded. When an oceanic plate subducts beneath a continental plate, rising masses of magma from the plate margin causes uplift in the land above it. Sedimentary layers of rock are somewhat plastic and can fold over the top of the rising igneous rock below. When terranes are caught between two plates and accreted onto a continent, folded mountains can form.

Examples of folded mountains include the Himalayas, the Appalachians, the Zagros in southern Iran, and the Alps in Europe. See the book *Earth Story* for a good illustration of the formation of the Himalayas and the Tibetan plateau.

Fault-block mountains – In Nevada, there are mountains that formed not when plates collided, but when a plate was stretched. The crust fractured and faulted many times, forming nearly parallel fault lines. Some sections rode up and others sank, creating the present Basin and Range Province. The section of the crust that sinks is called a graben, from German for a ditch, related to the word for grave. The portion that rises is called a horst, which literally translates "thicket" or "hedge", implying something that stands up and divides two areas.

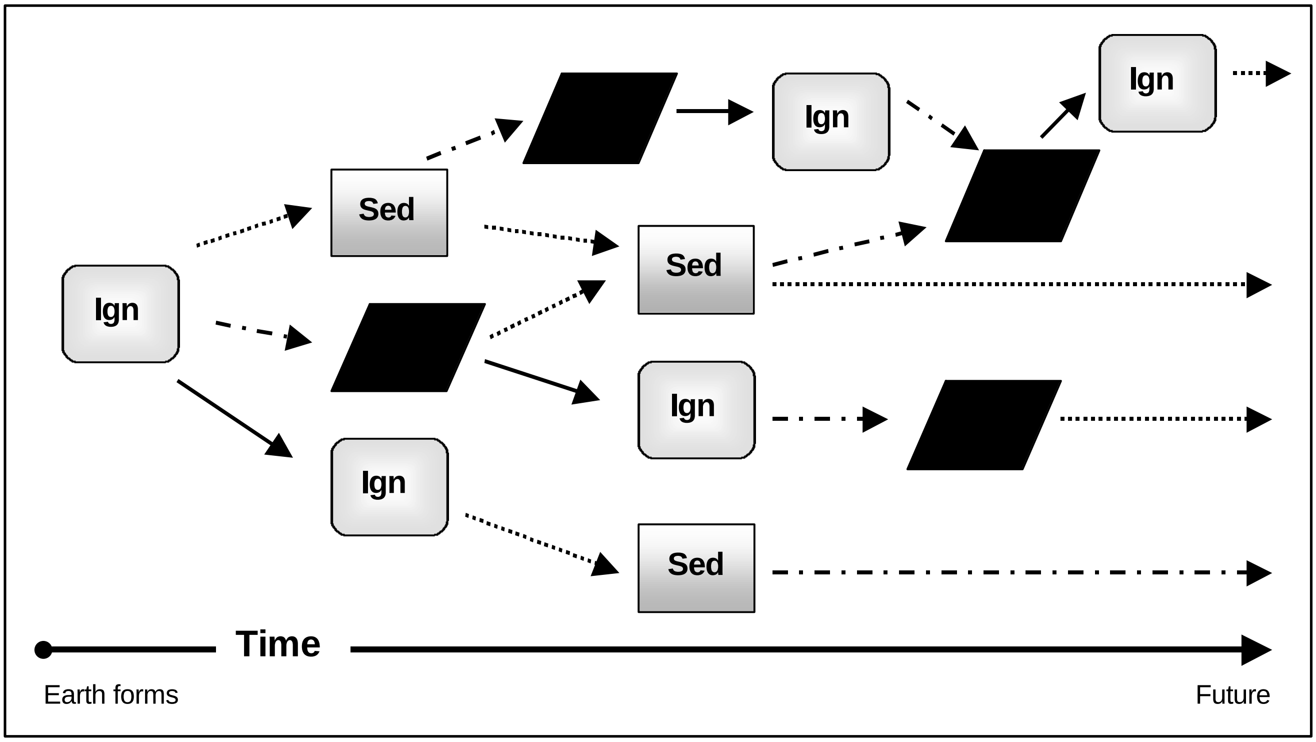
Other fault-block mountains form when the land on one side of a fault rises and the other side sinks. The Grand Tetons, the Sierra Nevada Mountains of California, and the Sandia Mountains, east of Albuquerque, N.M., are examples. "Sandia" means "watermelon" in Spanish. The mountains got their name because at sunset, the big crescent rock face turns reddish in the evening light and resembles a slice of watermelon. The bands of sedimentary rock (limestone) that arc across the summit look like the rind on the watermelon.

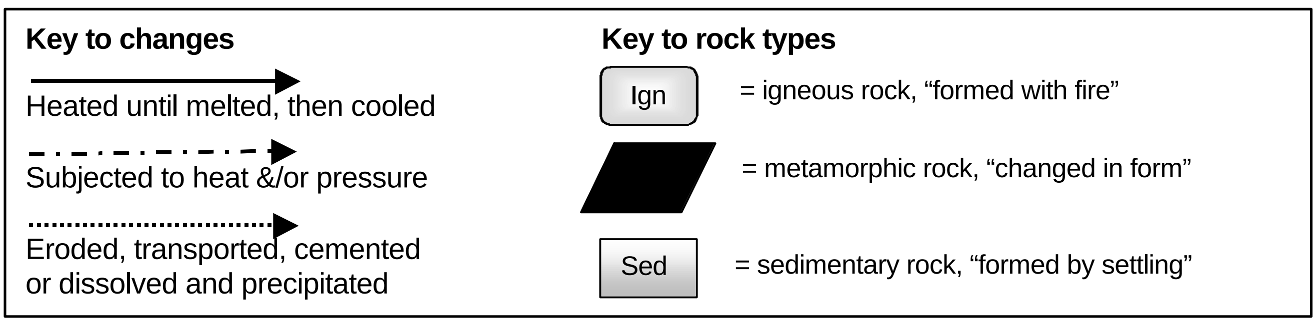
Mountains from magma – When oceanic plates dive beneath continental plates, great masses of rock melt and rise as magma. Magma can also rise in the middle of plates along rift zones. When the magma cools inside the Earth, it forms a body of rock called a pluton, named after Pluto, the Roman god of the underworld. When the land is rises and the over-lying rock erodes, the granite mass becomes mountains on the surface. A laccolith ("lake of rock") is a flat-bottomed dome of magma that has cooled inside the Earth. When it is exposed on the surface, it forms a mountain. See *Roadside Geology* of Colorado, New Mexico, or Utah for laccolith illustrations.

The largest plutons are batholiths ("deep rocks"), which cover 100 or more square kilometers. These intrusive igneous rocks form the core of mountain ranges along the west coasts of North and South America. The Cascade Mountains, the Sierra Nevada, and the Andes are granite-cored mountains that formed inland as subducting oceanic plates melted and the magma rose. In central Colorado there is a batholith that whose origin is less well understood. The Pikes Peak batholith is about a billion years old. It cooled very slowly, forming a pink granite with large crystals. Pikes Peak itself is the top of this batholith.

Sometimes the magma rises to the all the way to the surface and forms a volcano. This process occurs where plates converge, at spreading centers in the oceans and in rifting areas on land, and at hot spots. The highest peaks of the Cascades and the Andes are volcanoes, formed when magma extruded at the Earth's surface. Mt. Pinatubo in the Philippines and Mt. Fugiyama in Japan are volcanoes that formed in the islands behind converging ocean plates. The shape of the volcano depends on the chemistry of the magma and how much water and gas is dissolved in it. High silica magmas (50-75%) are more viscous and result in tall, conical peaks (with explosive eruptions), such as the volcanoes of the Andes. Low-silica, basaltic magmas, rich in iron and magnesium, flow easily and do not trap so much gas, so they don't explode. They form low, shield volcanoes, such as the Hawaiian volcanoes, whose magma source is a hot spot.❖

The Rock Cycle Unwound





Unwinding the Rock Cycle. This diagram of rock changes begins as the surface of the Earth solidifies. All rock is igneous at that time. From there, changes produce the other rock types. The igneous rocks are transformed into sedimentary, metamorphic, or new igneous rocks. Subsequently many rounds of change have happened.

To form sedimentary rocks, the parent material has to be eroded by water, wind, and/or ice, carried to another location, allowed to settle down, become compacted, and cemented together into a new rock. This process produces clastic sedimentary rocks, including sandstone and mudstone (shale). "Clast" is Greek for a fragment or broken piece. Clasts can be tiny particles, pebbles, or even boulders. There are also chemical sedimentary rocks, which form when parent materials are dissolved and later come out of solution (precipitate). Limestone and gypsum are examples.

Sedimentary and igneous rocks can **undergo physical** (larger, more tightly packed crystals) and **chemical** (new minerals) **changes** without totally melting. They become **metamorphic** rocks. Heat and pressure cause this change when the rocks are buried deep in the Earth or as they are compressed between converging plates. Magma can cook nearby rocks as it rises toward the surface, a process called contact metamorphism. Metamorphic rocks can be foliated (have a layered texture), or they can be uniform throughout and have a non-foliated texture.

Metamorphic or igneous rocks can **re-melt to form new igneous** rocks. Note that sedimentary rock does not go directly to igneous, since heat causes metamorphic changes in it first. Igneous rocks are classified by whether they solidified inside the Earth (intrusive) or on its surface (extrusive) and by their chemical composition. Felsic igneous rocks, high in feldspar and silica, are lighter-colored and less dense than the dark mafic igneous rocks, which are high in magnesium and iron. The rate the molten rocks cool affects the texture of the rocks. Rocks with large crystals, such as granites, cooled slowly. Fine-grained rhyolites and basalts cooled more quickly. Glassy obsidian cooled very quickly.

Tearing down structures – weathering, erosion, and gravity

The processes that tear down structures are easier to see than those that build them up. All around us, rock is **weathering**, both **physically**, as it is broken apart into smaller pieces, **and chemically**, as its minerals are dissolved or decomposed. Rock fragments are then transported and deposited somewhere else. The presence of water and vegetation greatly influence weathering. Plants can initiate weathering as well as retard the flow of water and sediments. A fresh road cut often exposes unweathered rock, which you can compare to the weathered rock of natural outcrops.

Rocks undergo **physical weathering**, i.e. **break apart** or disintegrate, from many causes including falling down hillsides, being tossed by waves, having water freeze and expand in cracks, and being split by tree roots. When a buried mass of rock rises to the surface, the release of pressure can cause the rock to fracture. Outer layers of granite peel off in a process known as exfoliation. The mass of loose rock pieces above the more solid bedrock is called the **regolith**.

Chemical weathering causes the rock to **change appearance or texture**. Feldspars break down to clays, tiny particles that are easily washed away. Iron in rocks can combine with oxygen and form rust. Sometimes water dissolves minerals from the rock. If carbon dioxide is dissolved in the water, it forms a solution of carbonic acid. This mild acid solution is especially good at dissolving limestone, producing karst topography (caves, caverns, towers, and sinkholes).

Rocks differ in their resistance to weathering. We see the result in places such as Bryce Canyon. Some minerals weather quickly. Feldspars, which make up about half of the minerals in the Earth's crust, weather easily to clays. Quartz is a mineral that resists weathering. This is why quartz sand is often left after rock weathers.

Weathered material may accumulate at the base of a slope or water or wind may carry it away. **Erosion is the transport** of weathered material. **Water is the great mover** of material on the Earth's surface. Streams and rivers transport large quantities of sediment. Glaciers move all sizes of rocks and carve landscapes. Thus the hydrologic cycle interconnects with the rock cycle. Wind also weathers rock (by sand blasting) and moves the resultant fragments. Gravity remains the driving force for erosion, with the Sun propelling the water cycle and winds.

Sometimes we can see a large section of hillside slide down, an example of the process called **mass movement** or **mass wasting**. The slope is what is being wasted. **Gravity** pulls a mass of material down a slope when it **overcomes friction and the bonding forces** in the rock. Mass movements can be slow or fast and include landslides, rock falls, rock glaciers, avalanches, mudflows, and creep. Two important factors that determine the type of mass movement are the steepness of the slope and the amount of water present to weight down and lubricate the material.

Geology words from all around the globe

Geology borrows terms from many languages. Here are some examples. (See also horst and graben, p. 3)
Aa – [AH-ah] – Hawaiian – sharp, blocky lava, from a magma with higher silica than basalt
Arête – [ah-RATE] - French, "knife edge"- a sharp ridge between cirques in glaciated mountains
Bajada – [bah-HAH-dah] – Spanish, "downgrade" – a line of joined alluvial fans at the base of desert mountains
Barchan – [bar-CAN] – Russian – a moving, crescent-shaped sand dune whose sides point downwind
Caldera – [call-DARE-ah] – Spanish, "caldron" – the basin at the center of a composite volcano crater
Caliche – [kah-LEE-chee] – Spanish, "flake of lime" – a calcium carbonate-cemented layer beneath the subsoil
Cirque – [serk] – French – a rounded, bowl-like basin in a mountain from which a glacier flows (or flowed)
Coquina – [koe-KEE-nah] – Spanish, "shellfish" – a limestone that is formed from mollusk shell fragments
Drumlin – Irish, "ridge" – a streamlined hill of glacial till; blunt end points in direction of glacial movement
Hoodoo – [WHO-do] – African origin – a column of rock shaped by differential weathering; has fanciful shapes
Jökulhlaup – [yolk-kul-LAP] – Icelandic – a glacial outburst flood caused by a volcano erupting beneath a glacier
Karst – name derived from the Krs plateau in Yugoslavia – a limestone area with sinkholes, pits, and caves
Lahar – [lah-HAR] – Javanese – a mudflow and/or debris flow of volcanic origin
Loess – [luss] – German – a loose, windblown deposit of fine soil; the particles were ground by a glacier
Nuée ardentes – [ny-AA ar-DAWNT] – French, "glowing cloud" – an avalanche of hot, volcanic ash and gases
Pahoehoe – [pa-HOY-HOY] – Hawaiian – a smooth, ropy lava, from a basaltic magma
Playa – [ply-YAH] – Spanish, "beach" – a flat-bottomed desert basin that may occasionally hold a shallow lake
Talus – [TAY-lus] – French from Latin, "ankle" – a pile of rock debris at the base of a mountain slope or cliff
Tarn – Middle English from Old Norse – a small lake in a cirque
Tombolo – [TOME-bah-low] – Italian – a sand or gravel bar that connects a small island with the mainland
Volcano – Italian, from the name of the god Vulcan
Yardang –[YAR-dang] Turkic – sharp, irregularly cut ridge, parallel to the prevailing wind, made by blowing sand

Book resources for studying the geologic cycle

Book resources for the geologic cycle are cataloged under several call numbers in the Dewey Decimal Classification. General geology is catalogued at 550. Books on specific geological phenomena and experiments in geology are in the 551 area. The book on the Grand Canyon (below) was catalogued under travel, at 917.9132.

Anderson, Peter. 1997. ***A Grand Canyon Journey: Tracing Time in Stone***. Franklin Watts. ISBN 0-531-20206-2. This book makes you feel as if you are there. A great geology story for elementary levels.

Branley, Franklyn M. and Marc Simont. 1985. ***Volcanoes*** (Let's-Read-and-Find-Out Science) Harper & Row. ISBN 0-690-04431-3. A good introduction to volcanoes for LE.

Ford, Brent A. 1996. ***Project Earth Science: Geology***. National Science Teachers Association. ISBN 0-87355-131-1. This has good background information, interesting experiments, and poems. Some activities could be demonstrations for LE, but most of this is UE and MS.

Gallant, Roy A. 1998. ***Limestone Caves.*** Franklin Watts. ISBN 0-531-20293-3. This book is a great resource for study of caves. UE-MS.

Gallant, Roy A. 1997. ***Sand on the Move: The Story of Dunes.*** Franklin Watts. ISBN 0-531-20334-4. Good quality information about the geology and biology of dunes, including how and why dunes form. UE-MS, read the introductory part to LE.

Goodwin, Peter. 1997. ***Landslides, Slumps, & Creep.*** Franklin Watts. ISBN 0-531-20332-8. This book introduces the process of mass wasting (mass movement). For elementary levels.

Haslam, Andrew and Barbara Taylor. 1997. ***Oceans*** (Make it Work! Geography). World Book and Two-Can Publishing. ISBN 0-7166-5110-6. Sections on the ocean floor and coastal landforms are useful for elementary study. Experiments model the movement of magma through the crust and erosion by waves. LE-UE.

Hiscock, Bruce. 1988. ***The Big Rock***. Atheneum, Macmillan Publishing Company. ISBN 0-689-31402-7. A wonderful story for LE, this follows a granite rock through billions of years of Earth's history.

Hooper, Meredith and Chris Coady. 1996. ***The Pebble in My Pocket: A History of Our Earth***. Viking Books. ISBN 0-670-86259-2. A timeline story that shows the life present as the pebble is formed and changed, starting 480 million years ago. Nicely done. LE.

Kaufmann, Jeffrey, et al. ***River Cutters***. GEMS unit. Lawrence Hall of Science, Univ. of CA., Berkeley. ISBN 0912511672. An experiment guide that helps UE-MS students discover how river erosion works.

Kittinger, Jo S. 1997. ***A Look at Rocks: From Coal to Kimberlite***. Franklin Watts. ISBN 0-531-20310-7. A good description of rock types and how they are formed. Includes clastic and chemical sedimentary, intrusive and extrusive igneous, and various metamorphic rocks. LE-UE.

Lamb, Simon and David Sington. 1998. ***Earth Story: The Shaping of Our World.*** Princeton Univ. Press. ISBN 0-691-00229-0. Good illustrations of plate tectonics (UE+), along with information on their discovery. MS-adult.

Roadside Geology series. Mountain Press Publishing Company, PO Box 2399, Missoula, MT 59806.

Sattler, Helen R. and Giulio Maestro. 1995. ***Our Patchwork Planet: The Story of Plate Tectonics.*** Lothrop, Lee & Shepard Books. ISBN 0-688-09313-2. A good introduction to plate tectonics for UE and MS.

Silver, Donald and Patricia Wynne. 1989. ***Earth, the Ever-changing Planet.*** Random House. ISBN 0-394-89195-3. Good illustrations and explanations of many Earth changes.

Zoehfeld, Kathleen and James Graham Hale. 1995. ***How Mountains Are Made.*** (Let's- Read-and-Find-Out Science, Stage 2). Harper Collins. ISBN 0-06-024510-7. A good explanation of mountain building and erosion for LE.

Internet resources

Volcano World has good lessons and links on plate tectonics and volcanoes. <http://volcano.und.nodak.edu/>

USGS Learning Web has online booklets, including *This Dynamic Earth* (plate tectonics) and ordering information. Geology maps and posters also available. If you don't have the Internet, call 1-888-275-8747 to order materials or resource lists. <www.usgs.gov/education/>

Track Star: Rock Cycle lists sites on rocks and the rock cycle. <http://www.scrtec.rtec.org/track/tracks/t00905.html>

The Good Earth has introductory geology. <http://newmedia.avs.uakron.edu/geology/ge/index.html>